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Original Article

CONTROL OF EXHAUST EMISSIONS FROM AN SI ENGINE WITH METALLIC (COPPER) COATING, FUEL BLEND AND CATALYTIC CONVERTER

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ABSTRACT

As the fossil fuels are fastly depleting and the pollution levels are increasing with their use, necessitating the search for alternate fuels. Alcohol is a potential and renewable fuel for SI engine, because its properties are compatible to those of gasoline fuels. Aldehydes, with their carcinogenic nature are one of the major pollutants, when SI engines are run with alcohols. As these pollutants poses serious health hazards for human beings and causes environmental pollution, their reduction assumed importance. This paper reported the exhaust emissions and their control from a single cylinder, air-cooled, Bajaj make, two-stroke SI engine, with a brake power of 2.2 kW at a rated speed of 3000 rpm with a compression ratio of 7.5:1. The exhaust emissions of CO and UBHC were determined with Netel Chromatograph CO/UBHC analyzer. Aldehyde levels were determined by DNPH method. The test fuels are pure gasoline and methanol blended gasoline (80% gasoline and 20% methanol, by volume). The crown surface of piston and inside surface of the cylinder head were coated with copper for a thickness of 300 microns. A catalytic converter with air injection with sponge iron (SPI)/manganese (Mn) ore as catalyst was provided to the engine. In comparison with the conventional engine (CE) with experimental fuels, the performance of catalytically activated engine was found to be improved. **Air injection in to catalytic converter significantly decreased the exhaust emissions with sponge iron (SPI) as catalyst over manganese (Mn) ore.**

KEYWORDS: *SI Engine, Alcohol, CO, UBHC & Aldehydes*

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INTRODUCTION

On the basis of the number of automotive vehicles being used by the public, the civilization of a particular country is measured. The population explosion imposes expansion of the cities to larger areas and common man is forced to travel through long distances, these days even for their routine works. This in turn is causing an increase in vehicular population at an alarming rate, thus bringing in pressure on government to spend huge foreign currency for importing crude petroleum to meet the fuel needs of the automotive vehicles. For individual transport, SI engine is preferred to CI engine. Though two-stroke engine develops more power when compared with four-stroke engine, it faces criticism, as it emits higher pollution levels. Alcohols are the promising substitutes for gasoline.

The use of alcohol in small quantities poses no problem in SI engines. Performance of the engine can also be improved with the change of fuel composition with alcohol-gasoline blends in SI engines. Out of the two alcohols available (methyl alcohol and ethyl alcohol), methyl alcohol is preferred to ethyl alcohol, as it is not harmful. Methyl alcohol has got properties compatible to those of gasoline. If alcohol is blended with gasoline up to 20% by volume, no major engine design modification is necessary. Many investigations were carried out [1-4] on

SI engines to improve the performance by varying spark plug timing, increasing the compression ratio and coating the engine components with high conductive material like copper. Out of these methods, copper coating was a simple technique and can easily be adopted. As copper has high thermal conductivity, it improves preflame reactions and turbulence in SI engines.

When SI engines are run with alcohols, the major emissions are CO and UBHC, besides aldehydes. CO is formed due to incomplete combustion. When excess fuel is present and little oxygen is available, CO is formed. UBHC is formed due to 'quenching effect'. The fuel will settle in the crevices of the piston and on the inner walls of the combustion chamber, which will come out during the exhaust stroke in the form of UBHC. When the engine is run with alcohols, aldehydes are formed as intermediate compounds in the combustion reactions. Aldehydes are carcinogenic in nature.

As the exhaust emissions of CO (%), UBHC (ppm) and aldehydes (% concentration) cause harmful health hazards [5-9] on human beings and on environment [6], necessary steps are to be taken in the form of changing the fuel composition or engine design modification [10-11] or both, to decrease them. Coupling catalytic converter [12-15] to the engine is a simple technique to decrease the exhaust emissions from the engine. However, the catalytic converters are generally provided with high cost catalysts such as platinum, rhodium, palladium etc. Hence catalytic converters are to be provided with suitable and cheap catalysts like sponge iron (SPI)/ manganese (Mn) ore to reduce the exhaust emissions [16-20] from the engine.

The main emphasis of any engine designer is to run the engine efficiently with higher thermal efficiency and lower harmful exhaust emissions. The author has attempted in this direction to improve the engine efficiency as well as to reduce the exhaust emissions. The exhaust emissions were determined with experimental fuels with various configurations of the engine and compared with base engine.

METHODS

The two-stroke, single-cylinder, air-cooled, Bajaj make, petrol engine (square engine) of brake power 2.2 kW at 3000 rpm with a compression ratio of 7.5:1 is used in the experimentation. The test fuels used for experimentation are pure gasoline and methanol blended gasoline (20% of methanol blended with 80% of gasoline, by volume). The schematic diagram of experimental set up employed to determine the exhaust emissions is shown in Figure 1.

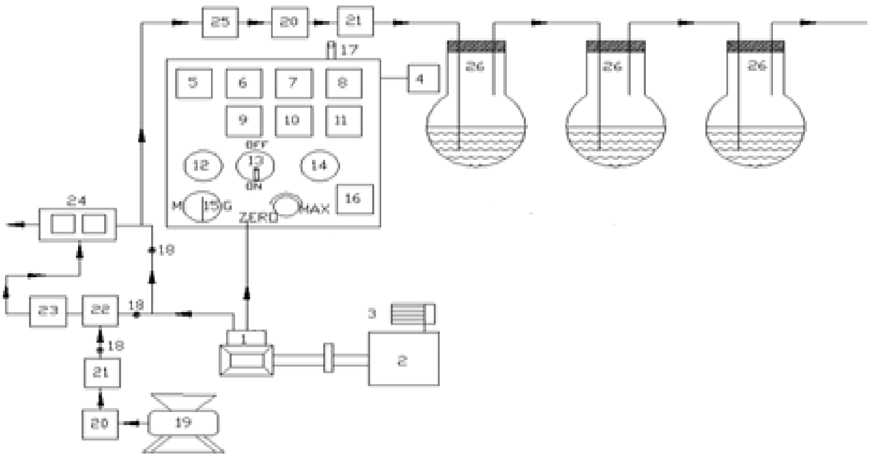

Figure 1: Experimental Setup

1. Engine, 2. Electrical swinging field dynamometer, 3. Loading arrangement, 4. Fuel tank, 5. Torque indicator/controller sensor, 6. Fuel rate indicator sensor, 7. Hot wire gas flow indicator, 8. Multi channel temperature indicator, 9. Speed indicator, 10. Air flow indicator, 11. Exhaust gas temperature indicator, 12. Mains ON, 13. Engine ON/OFF switch,14. Mains OFF, 15. Motor/Generator option switch, 16. Heater controller, 17. Speed indicator, 18. Directional valve, 19. Air compressor, 20. Rotometer, 21. Heater, 22. Air chamber, 23. Catalytic chamber, 24. CO/HC analyzer, 25. Filter, 26. Round bottom flasks containing DNPH solution.

A bond coating of NiCoCr alloy was applied for a thickness of about 100 microns using an 80 kW METCO flame spray gun. Over the bond coating copper 89.5%, Aluminium 9.5% and iron 1.0% was coated for 300 microns thickness (Plate-1).

Plate 1: **Photographic View of Copper Coated Piston, Liner and Copper Coated Cylinder Head**

The coating had very high bond strength that, it does not wear off even after 50 hrs of continuous operation [12]. Pollution levels of CO and UBHC are measured with Netel Chromatograph CO/HC analyzer. DNPH method [10] is employed for measuring aldehydes in the experimentation. The exhaust of the engine is bubbled through 2, 4 Dinitrophenyl Hydrazine (2, 4 DNPH) solution. The hydrazones formed are extracted into chloroform and are analyzed by employing high performance liquid chromatography (HPLC) to find the percentage concentration of formaldehyde and acetaldehyde in the exhaust of the engine. A catalytic converter (Figure 2) was fitted to the exhaust pipe of the engine.

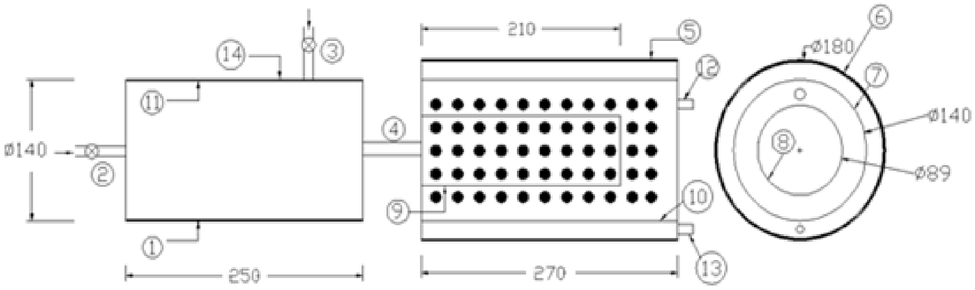

Figure 2: Catalytic Converter

1. Air chamber, 2. Inlet for air chamber from the engine, 3. Inlet for air chamber from the compressor, 4. Outlet for air chamber, 5. Catalytic chamber, 6. Outer cylinder, 7. Intermediate-cylinder, 8. Inner-cylinder, 9. Inner sheet, 10. Intermediate sheet, 11. Outer sheet, 12. Outlet for exhaust gases, 13. Provision to deposit the catalyst, and 14. Insulation.

The exhaust gases from the engine enter the inner cylinder of the catalytic converter and come out of the holes

provided on the circumference of the inner cylinder and pass through catalyst provided in the annular space between the inner cylinder and intermediate cylinder. After the catalyst action, the exhaust gases comes out of the circumference holes provided on intermediate cylinder and exits to the atmosphere from the outlet provided to the outer cylinder.

RESULTS AND DISCUSSIONS

Investigations were made on the base engine and on the catalytically activated engine with experimental fuels. The results obtained on the aspects of exhaust emissions and their control were analyzed and discussed below.

The variation of CO emissions (%) with BMEP in the base engine and catalytically activated engine with experimental fuels was shown in Figure 3.

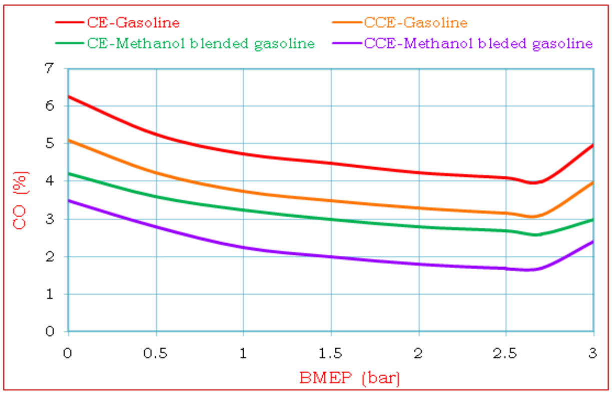

Figure 3: Variation of CO (%) Emissions with BMEP (Bar) in CE and CCE with Test Fuels

CE- conventional engine**:** **CCE-** Copper coated engine: **BMEP**-Brake mean effective pressure: **CO**: Carbon monoxide emissions

From the Figure 3, it is observed that, methanol blended gasoline decreased CO emissions at all loads when compared to pure gasoline operation in CE and CCE, as fuel-cracking reactions [12, 21] are eliminated with methanol. The combustion of alcohol produces more water vapor than free carbon atoms as methanol has lower C/H ratio of 0.25 against 0.44 of gasoline. Methanol has oxygen in its structure and hence its blends have lower stoichiometric air requirements compared to gasoline. Therefore more oxygen that is available for combustion with the blends of methanol and gasoline, leads to reduction of CO emissions. Methanol dissociates in the combustion chamber of the engine forming hydrogen, which helps the fuel-air mixture to burn quickly. This increases combustion velocity, which brings about complete combustion of carbon present in the fuel to CO_2 and also CO to CO_2. This makes leaner mixture more combustible, causing reduction of CO emissions. CCE reduces CO emissions in comparison with CE. Copper or its alloys acts as catalyst in combustion chamber, whereby facilitates effective combustion of fuel leading to formation of CO_2 instead of CO.

The variation of UBHC emissions (ppm) with BMEP in the base engine and catalytic coated engine with experimental fuels was presented in the Figure 4.

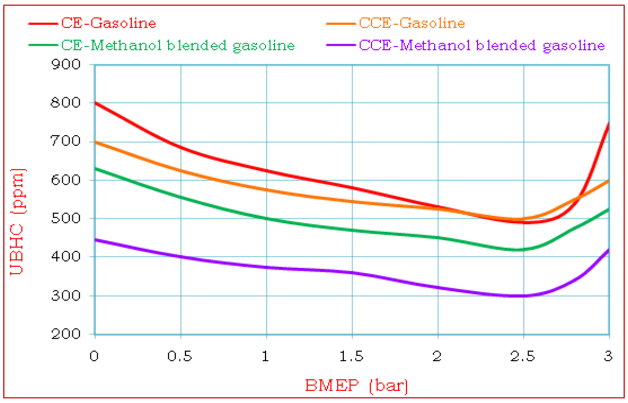

Figure 4: Variation of Unburnt Hydrocarbons (UBHC) (ppm) Emissions with BMEP (Bar) in CE and CCE with Test Fuels

From the Figure 4, it is observed that, UBHC emissions followed the same trend as CO emissions in CCE and CE with both test fuels, due to increase of flame speed with catalytic activity and reduction of quenching effect with CCE. Catalytic converter reduced pollutants considerably with CE and CCE and air injection into catalytic converter further reduced pollutants. In presence of catalyst, pollutants get further oxidised to give less harmful emissions like CO_2. Sponge iron decreased CO emissions considerably when compared with manganese ore in both versions of the engine with different configurations of the engine. Similar trends are observed with pure gasoline operation on CCE [12, 21].

The data of CO emissions (%) from CE and CCE with test fuels under various sets of catalytic converter with SPI/Mn ore catalyst was presented in the Table 1.

Table 1: Data of CO Emissions (%) at Full Load Operation

Operating Condition of Catalytic Converter	CE				CCE			
	Gasoline		Methanol Blended Gasoline		Gasoline		Methanol Blended Gasoline	
	Sponge Iron	Manganese Ore	Sponge Iron	Manganese Ore	Sponge Iron	Manganese Ore	Sponge Iron	Mangan ese Ore
Set-A	5	5	3	3	4	4	2.4	2.4
Set-B	3	4	1.8	2.1	2.4	3.2	1.44	1.92
Set-C	2	3	1.2	1.5	1.6	2.4	0.96	1.44

Set-A- Without catalyst and without air injection, **Set-B**- With catalyst and without air injection, **Set-C-** With catalyst and with air injection

From the Table 1, it can be observed that CO emissions deceased considerably with catalytic operation in set-B with methanol blended gasoline and further decrease in CO is more pronounced with air injection with the same fuel. Large reduction of CO is achieved with the use of converter and air injection further decreased the pollutants in the exhaust at all loads with all the above sets. The temperature of the catalyst is maintained at room temperature (30^oC) and air flow rate (Set-C) is maintained as 120 lit/hr. The effective combustion of the methanol blended gasoline itself decreased CO emissions in both configurations of the engine. Sponge iron decreased CO emissions effectively when compared with the manganese ore in both versions of the engine with both test fuels.

The data of UBHC emissions (ppm) from CE and CCE with test fuels under various sets of catalytic converter with SPI/Mn ore catalyst was presented in the Table 2.

Table 2: Data of UBHC Emissions (ppm) at Full Load Operation

Operating Condition of Catalytic Converter	CE				CCE			
	Gasoline		Methanol Blended Gasoline		Gasoline		Methanol Blended Gasoline	
	Sponge Iron	Manganese Ore	Sponge Iron	Manganese ore	Sponge Iron	Manganese Ore	Sponge Iron	Manganese Ore
Set-A	750	750	525	525	600	600	420	420
Set-B	450	600	315	420	360	480	252	335
Set-C	300	450	210	315	240	360	168	250

From the Table 2, it is seen that, the trends observed with UBHC emissions are similar to those of CO emissions in both versions of the engine with both test fuels. Sponge iron is more effective in reducing UBHC emissions in both versions of the engine with different test fuels.

The data of formal dehyde emissions (% concentration) from CE and CCE with test fuels under various sets of catalytic converter with SPI/Mn ore catalyst was presented in the Table 3.

Table 3: Data of Formaldehyde Emissions (% Concentration) at Full Load Operation

Operating Condition of Catalytic Converter	CE				CCE			
	Gasoline		Methanol Blended Gasoline		Gasoline		Methanol Blended Gasoline	
	Sponge Iron	Manganese Ore	Sponge Iron	Manganese Ore	Sponge Iron	Manganese Ore	Sponge Iron	Manganese Ore
Set-A	9.1	9.1	23.6	23.6	6.8	6.8	13.6	13.6
Set-B	6.3	8.2	10.8	12.6	4.1	5.9	10.2	12
Set-C	3.5	5.5	8	10.1	3.2	5	5.5	7.2

From the table 3 it is observed that formaldehyde emissions increased drastically with methanol blended gasoline operation in both versions of the engine in comparison with pure gasoline operation. However, the percentage increase in formaldehyde emissions is less with CCE when compared with CE. This shows that CCE decreases formaldehyde emissions considerably. With the both test fuels, CCE drastically decreased formaldehyde emissions in comparison with CE. The intermediate compounds will not be formed is the reason for decrease of formaldehyde emissions in CCE. This shows combustion is improved with catalytic activity in CCE which decreased formaldehyde emissions. Formaldehyde emissions decreased with Set-B operation and further decreased in Set-C operation in both versions of the engine with both test fuels. This is due to increase of oxidation reaction with the use of catalyst and air which caused reduction of formaldehyde contents. Set-B operation with catalytic converter decreased pollutants considerably with both test fuels with different configuration of the engine, while further decrease in pollutants is pronounced with Set-C operation. This is due to improved oxidation reaction of the catalyst and air. Sponge iron is more effective in reducing formaldehyde emissions, when compared with manganese ore.

The data of acetaldehyde emissions (% concentration) from CE and CCE with test fuels under various sets of catalytic converter with SPI/Mn ore catalyst was presented in the Table 4.

Table 4: Data of Acetaldehyde Emissions (% Concentration) at Full Load Operation

Operating condition of catalytic converter	CE				CCE			
	Gasoline		Methanol Blended Gasoline		Gasoline		Methanol Blended Gasoline	
	Sponge iron	Manganese ore	Sponge iron	Manganese ore	Sponge iron	Manganese ore	Sponge iron	Manganese ore
Set-A	7.7	7.7	12.3	12.3	4.9	4.9	9.3	9.3
Set-B	4.9	7.2	6.5	8.5	3.5	5.3	7.7	9.5
Set-C	2.1	4.3	3.8	5.6	1.4	3.1	3.9	5.6

From the Table 4 it is observed that, the acetaldehyde emissions decreased with the use of catalytic converter coupled with air injection with both test fuels with both versions of the engine. CCE effectively reduced the acetaldehyde emissions in comparison with CE with both test fuels. This is due to improved combustion so that intermediate compounds will not be formed at all during the combustion.

CONCLUSIONS

The following conclusions were drawn from the experimentation:

1. Methyl alcohol blend in the CCE decreased CO emissions and UBHC emissions by 52% and 44% respectively when compared to CE with pure gasoline.
2. With pure gasoline, CCE decreased formaldehyde emissions and acetaldehyde emissions by 25.3% and 36.4% respectively in comparison with CE.
3. CCE decreased formaldehyde emissions and acetaldehyde emissions by 42.4% and 24.4% respectively with methyl alcohol blend when compared to CE.
4. CCE with methyl alcohol blend and sponge iron catalyst decreased the CO emissions and UBHC emissions by 71% and 67% respectively without air injection, while the emissions were decreased by 81% and 78% respectively with air injection in comparison with CE.
5. With methyl alcohol blend and manganese ore catalyst, CCE decreased the CO emissions and UBHC emissions by 62% and 56% respectively without air injection, while they were decreased by 72% and 67% respectively with air injection, in comparison with CE.
6. Formaldehyde emissions and acetaldehyde emissions, from CE and CCE using both experimental fuels, were decreased with injection of air in to catalytic converter.
7. Sponge iron catalyst was more effective in reducing exhaust emissions in comparison with manganese ore for both configurations of the engine using experimental fuels.

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